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Using Super Conductive Fault Current Limiter to Retrieve the Protection Coordination of Networks in the Presence of Distributed Generation

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ABSTRACT
Distributed Generation Resources are increasingly used in distribution systems due to their great benefits. The application of DG, however, can cause different problems such as miss-coordination, false tripping, blinding and reduction of reach of protective devices. Using superconducting fault current limiters (SFCLs) is one of the best methods to minimize these problems comparing to the other conventional methods. In this paper coordination problem of overcurrent relays in the presence of distributed generation resources. The presented method is implemented on IEEE 30 buses network and the efficiency of the proposed approach is tested and proved.

Keywords: Distributed Generation, Fault Current Limiter, Overcurrent Relay, Protection Coordination

1. INTRODUCTION

In recent years, mainly due to environmental concerns and in preparation for an expected shortage of traditional fossil fuel based energy, distributed generation (DG) based on renewable energy sources is attracting more and more attention.. Along with its benefits, distribution generation may have negative impacts on the distribution system since it increases the fault current level and changes the direction of the flow of current in the lines during the fault situation. The most important negative consequences can be mentioned as false tripping, blinding and/ or reduction of reach of protective devices and missing the coordination between such devices. This side effect will reduce the degree of immunity of the system.

Many corrective actions are performed to reduce the negative effects of distribution generation units on the distribution system such as checking the coordination of the protection devices every time that DG connects to the system (Hadjsaid 1999), using microprocessor-based reclosers (Brahma 2002), taking advantage of adaptive protection (Brahma 2004), decreasing the generation capacity or delayed operation of DGs and changing the circuit breakers and protective devices (Tailor 2008). These methods impose lots of expenses, are complex and do not use the total capacity of DG units; therefore, they are not accepted widely. Using Fault Current Limiters (FCL) is a new solution to reduce the undesired impacts of DG on the distribution system. In the normal condition of the system, FCL will cause no voltage drop or loss in the system; while in fault condition, it will decrease the mentioned impacts of the DG. By the use of FCLs, the number of protection devices which should be changed after installing DG in the system will be minimized and the coordination of the protection system would be restored. Moreover, this method is not so costly and does not need performing complicated protection algorithms. In (Sato 2007) the increase of the fault current with the introduction of DGs can be limited using SFCL. Further the instantaneous voltage sag on the normal lines can be prevented

In this paper problems of implementing DG resources are analyzed and the impact of DG on Over Current Relays (OCR) is presented. In order to mitigate these problems FCL is used. Coordination problem of overcurrent relays in the presence of DG resources are solved by presenting a new approach. The presented method is implemented on IEEE 30 buses network and the efficiency of the proposed approach is tested and proved.

2. NEGATIVE EFFECTS OF DG ON THE DISTRIBUTION PROTECTION SYSTEM

Installing a DG unit in the distribution network will decrease the Thevenine`s impedance seen from the fault point, since a new impedance is being paralleled to the system, which will increase the fault current level. Furthermore, presence of DG in a radial distribution network, in which all the currents are flowed from the source to the consumers, may change the current direction in some lines. The most important negative effects of the DG on the protection system of the distribution network will be reviewed in the following sections (Feng 2010):

A.Miss-coordination Between The Protective Devices

Since the DG unit will increase the fault current flowed through the protective devices, the coordination between protective devices may be lost and there may be a disorder in the sequence of operation of the main and backup protection systems.

TABLE I. PROTECTIVE PARAMETERS OF THE SYSTEM

Time Multiplier Setting	TMS	Objective Function	OF
Current Setting	Is	Relay operation time	trel
Maximum Fault Current	I_{MF}	Recloser operation time	trec
Minimum Fault Current	I_{mf}	Backup Protection	B
Minimum Melting Time	MMT	Primary Protection	P
Maximum Clear Time of Fuse	MCT	Number of Relay	nrel
Delayed Operation	D	Number of Recloser	nrec
Fast Operation	F	Number of Fuse	nfus

B.Protection System Blinding

This case may happen when the impedance between the beginning of the initial feeder of the network and the fault point is significantly more than the impedance between the DG unit and this point. In this situation, the fault current from the main source decreases according to the current division law between two paralleled impedances, which may be less than the setting current of the protection device.

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C. False Tripping of The Protective Devices

Due to the presence of the DG units in the distribution network, false tripping is mainly caused by the current flowed through the protective devices in the opposite direction in which they have been set and may cause unnecessary interrupt of part of the network.

D. Reduction of Reach of Protective Devices

Presence of DG units in distribution network may cause the upstream protective devices to sense a portion of the actual fault current. Hence, these devices will have inappropriate operation due to this reduction of their reach. The effect of DG units on the power system depends on several factors such as the technology, size and the capacity of the unit, the location of installing the unit and how the unit is connected to the system. Recent studies show that, among all other technologies, the units which use synchronous generators have the most negative impact of increasing the fault current. In order to consider the worst case in the presented study, the DG capacity is assumed to be the maximum available, which is a function of the total load of the feeder. Common installation points of DG are selected based on the environmental conditions, fuel limitations and different positions with respect to the protective devices.

E. Detecting The Worst Case for The Protection System

The number of all possible protection problems and the worst case among them should be defined in order to minimize the effect of each of them on the distribution network; since satisfying the protection criteria in the worst case will assure the prevention of other problems caused by the presence of DGs in the network. After defining the protection-evaluating indices, detection of the worst case is consisted of determining the worst fault location and finding the worst protective device or the worst pair of protective devices. Fig. 1 shows the effect of DG on increasing the fault current in case of a downstream fault. As seen in this figure, the impedance from the main generation/ source to the DG common coupling point is ZNet and the impedance from the DG source to this point is ZDG. Zth denotes the Thevenine`s impedance seen from the main source. According to these notations, the contribution of the main source and the DG unit to the fault current are obtained from the following equations, denoted by INet and IDG, respectively.

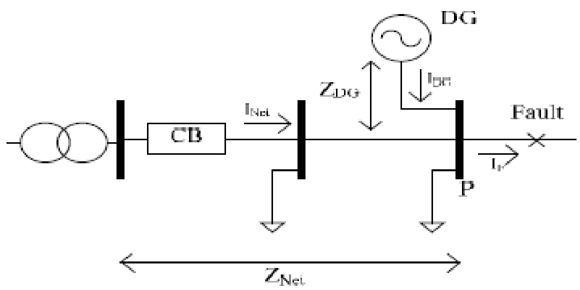

Figure 1 The Typical System to Show the Participation of the DG in the Fault Current

$$I_{DG}=\frac{Z_{th}+Z_{Net}}{Z_{th}+Z_{Net}+Z_{DG}}I_F \qquad I_{Net}=\frac{Z_{DG}}{Z_{th}+Z_{Net}+Z_{DG}}I_F$$

According to the above equations, the negative effect of DG on the protection system becomes more severe by an increase in the distance from the main source to the fault point, hence an increase in the amount of ZNet, and also a decrease in the distance between DG and the fault point which is the same as a decrease in the amount of ZDG with an increase of the capacity of the unit.

3. APPLICATION OF SFCL

A Fault Current Limiter (FCL) is a device for detecting, triggering and limiting fault currents in power systems. An ideal FCL works in low impedance at standby state thus causes little contribution to power loss of a healthy system. However, it rapidly converts to a high impedance when a fault occurs, decreasing the fault current. Among all types of FCL, the usefulness and usability of Super-

conducting Fault Current Limiters (SFCLs) are widely investigated due to the advantage of inherent self-triggering, fast response and self-recovery. The quenching and recovery characteristics of a resistive type SFCL can be described as follows:

$$R_{SFCL}(t)=\begin{cases} 0 & t<t_f \\ R_n\left[1-\exp\left(1-\dfrac{t-t_f}{T_F}\right)\right]^{\frac{1}{2}} & t_f<t<t_r \\ a(t-t_r)+b & t>t_r \end{cases}$$

In this Equation Rn refers to the maximum resistance of the specific SFCL, TF refers to the time constant of transition from the superconducting state to the non-super- conducting state, while tf and tr are the time intervals for SFCL starting quenching and starting recovery respectively. Variables a and b are constants related to recovery characteristic.

The impact of the SFCL on a connected DG unit during fault conditions is determined by its current limiting performance on the DG current. A model of DG-SFCL unit has been developed in the environment of PSCAD/EMTDC (El-Khattam 2008). To illustrate the SFCL performance Figure 2 depicts the DG fault current contribution Ia resulting from a simulated fault in the network, with Ia0 depicting the non-limited DG fault current contribution as a reference. Here, the quenched impedance of SFCL is selected equals to the line impedance of the small system.

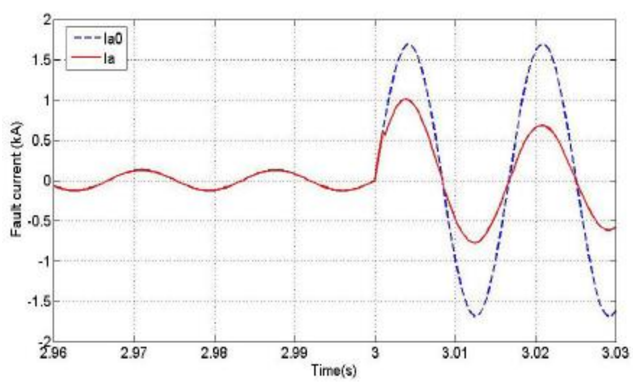

Figure 2 DG fault current limitation by a SFCL

As can be seen in Figure 2, the peak value of fault current Ia0 before the installation of a SFCL (approximately 1.8 kA) is more than 10 times of the normal operation current (the magnitude is around 150 A). By in-stalling a SFCL in series to the DG, this fault current peak can be limited by around 50% (being reduced to about 1 kA) of its non-limited value. Note that the cur-rent limiting performance greatly depends on the non-superconducting impedance of SFCL, which will be discussed later on.

4. SIMULATION RESULTS

A. Case Study

The test network used in this study is IEEE 30 bus network. The single line diagram of this network is illustrated in the figure 3. As illustrated, this network consists of two 32 kV and 132 kV voltage levels. Further information of this network is presented in (Christie 2008).

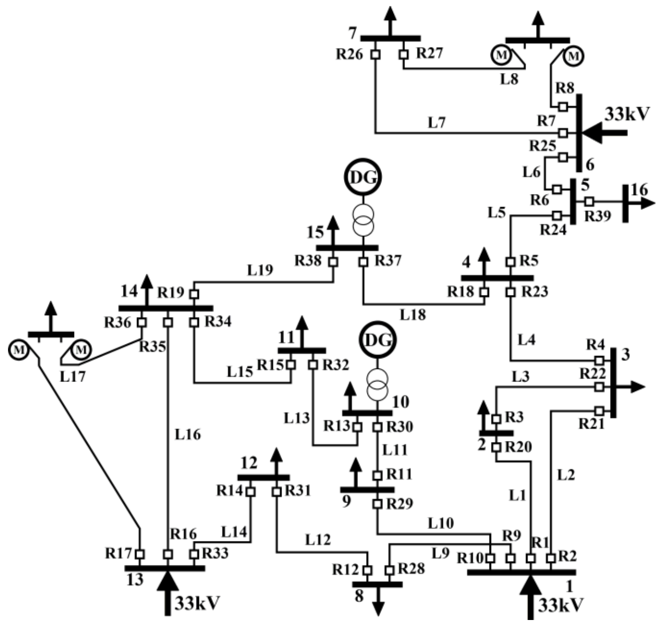

Figure 3 Distribution section of IEEE 30 bus test network

Information of lines, generators and transformers of the IEEE 30 bus network is presented in (Christie 2008). There are two directional OCR at the ended and in the beginning of each line. Therefore, there are 38 directional OCR in the network. Equation of characteristics of OCR and earth fault relays is considered as the following equation.

$$\frac{t}{\mathrm{TSM}} = \frac{A}{(M)^{C} - 1} + B, \quad \left(M = \frac{I_{sc}}{I_b} \right)$$

B. Simulation Results

Installing DG resources increases short circuit level of the network and especially in the buses which are closer to the resources. This increase in the short circuit level of buses, reduces the operation time of relays. Operation time of all main and back up relays of the network, and time difference of each paired relays are presented in the Table 2.

Table 2 The Operation Time of OCR in the Existence of DG and Without FCL

The number of backup relay	The number of main relay	The operation time of backup relay	The operation time of main relay	Time difference of the main and back up relays	The number of backup relay	The number of main relay	The operation time of backup relay	The operation time of main relay	Time difference of the main and back up relays
1	3	0.777	0.517	0.060	20	9	0.917	0.846	-0.129
2	22	1.640	0.986	0.454	20	10	0.938	0.790	-0.052

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The number of backup relay	The number of main relay	The operation time of backup relay	The operation time of main relay	Time difference of the main and back up relays	The number of backup relay	The number of main relay	The operation time of backup relay	The operation time of main relay	Time difference of the main and back up relays
2	4	1.647	0.847	0.600	21	1	0.692	0.550	-0.058
3	21	0.569	0.214	0.155	21	9	0.667	0.846	-0.379
3	4	0.567	0.847	-0.480	21	10	0.678	0.790	-0.312
4	5	1.374	0.595	0.579	22	20	1.070	0.356	0.515
4	18	1.371	0.849	0.322	23	21	0.800	0.214	0.386
5	6	1.012	0.754	0.058	23	22	0.795	0.986	-0.391
6	7	0.940	0.719	0.021	24	23	1.294	0.494	0.601
6	8	0.951	0.970	-0.039	24	18	1.303	0.849	0.253
7	27	1.525	0.233	1.092	25	24	2.022	0.848	0.975
8	26	2.030	0.239	1.591	28	1	1.025	0.550	0.275
9	12	1.125	0.647	0.278	28	2	1.036	0.920	-0.083
10	11	1.419	0.887	0.332	28	10	1.047	0.790	0.057
11	13	1.001	0.736	0.066	29	1	0.834	0.550	0.084
12	14	0.959	0.627	0.132	29	2	0.854	0.920	-0.266
13	15	0.889	0.640	0.049	29	9	0.837	0.846	-0.209
14	16	0.910	0.614	0.096	30	29	0.617	0.371	0.046
14	17	0.944	0.583	0.160	31	28	1.119	0.802	0.117
15	35	0.881	0.636	0.045	32	30	0.833	0.553	0.080
15	36	0.903	0.553	0.151	33	31	1.252	0.802	0.249
15	19	0.888	0.505	0.183	34	32	0.994	0.708	0.086
16	34	0.913	0.667	0.045	35	33	1.009	0.764	0.045
16	36	0.923	0.553	0.170	35	17	1.070	0.583	0.287
16	19	0.912	0.505	0.207	36	33	1.595	0.764	0.630
17	34	1.205	0.667	0.338	36	16	1.640	0.614	0.826
17	35	1.203	0.636	0.367	37	23	1.038	0.494	0.344
17	19	1.204	0.505	0.500	37	5	1.045	0.595	0.250
18	38	1.195	0.703	0.292	38	34	0.862	0.667	-0.005
19	37	0.664	0.771	-0.307	38	35	0.857	0.636	0.021
20	2	0.993	0.920	-0.126	38	36	0.869	0.553	0.117

According to Table 2 there are 14 cases in which the coordination of OC pair relays is lost.

5. CONCLUSION

In this paper, superconductive fault current limiter is used in series with the DG unit to minimize the negative effects of the DG on the protection system of the distribution network. The main negative effects of DG on the protection system are miss-coordination,

false tripping, blinding and reduction of reach of the protection devices. The presented method is tested on IEEE 30 bus network and results proved that the coordination between OC paired relays is achieved after implementing FCLs with acquired impedances.

REFERENCES

1. N. Hadjsaid, J. F. Canard, and F. Dumas, "Dispersed generation impact on distribution networks", IEEE Comput. Appl. Power, Vol. 12, No. 2, pp. 22-28, Apr. 1999.
2. S. M. Brahma and A. A. Girgis, "Microprocessor based reclosing to coordinate fuse and recloser in a system with high penetration of distributed generation", in Proc. IEEE Power Eng. Soc.Winter Meeting, Vol. 1, pp. 453-458, 2002.
3. S. M. Brahma and A. A. Girgis, "Development of adaptive protection scheme for distribution systems with high penetration of distributed generation", IEEE Trans. Power Del., Vol. 19, No.1, pp. 56-63, Jan. 2004.
4. S. Chaitusaney and A. Yokoyama, "Impact of protection coordination on sizes of several distributed generation sources", 7th International Power Engineering Conference, Vol. 2, pp. 669-674, 29 Nov.-2 Dec. 2005.
5. K. Tailor and A. H. Osman, "Restoration of fuse-recloser coordination in distribution system with high DG penetration", IEEE Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, pp. 1-8, 20-24 Jul. 2008.
6. T. Sato, M. Yamaguchi, T. Terashima, S. Fukui, J. Ogawa, H. Shimizu, and T. Sato, "Study on the effect of fault current limiter in power system with dispersed generators", IEEE Trans. on Applied Superconductivity, Vol. 17, no. 2, pp. 2331-2334, June 2007.
7. W. J. Park, B. C. Sung, K. B. Song, and J. W. Park, "Parameter optimization of SFCL with wind-turbine generation system based on its protective coordination", IEEE Trans. on Applied Superconductivity, Vol. 21, No. 3, pp. 2153 – 2156, June 2011.
8. S. H. Lim, J. S. Kim, M. H. Kim and J. C. Kim, "Improvement of protection coordination of protective devices through application of a SFCL in a power distribution system with a dispersed generation", IEEE Trans. on Applied Superconductivity.
9. W. El-Khattam and T. S. Sidhu, "Restoration of directional overcurrent relay coordination in distributed generation systems utilizing fault current limiter", IEEE Trans. on Power Delivery, Vol. 23, No. 2, pp. 576-585, April 2008.
10. R. Christie, "Power Systems Test Case Archive", College of Engineering, University of Washington, WA, Available: www.ee.washington.edu/research/pstca, 2008.
11. M. A. Hannan and A. Mohamed, "Performance evaluation of solid statefault current limiters in electric distribution system," in Research and Development, 2003. SCORED 2003. Proceedings. Student Conference on, pp. 245-25, 2003.
12. Y. Feng, Johnson, E., Saadeh, O., Balda, J. C., et al., "Impact of solid-state fault current limiters on protection equipment in transmission and distribution systems," in Transmission and Distribution Conference and Exposition, 2010 IEEE PES, pp. 1-6, 2010.
13. M. M. R. Ahmed, Putrus, G., Li, Ran, Penlington, R., "Development of a prototype solid-state fault-current limiting and interrupting device for low-voltage distribution networks," Power Delivery, IEEE Transactions on, Vol. 21, pp. 1997-2005, 2006.
14. Z. Lu, Jiang, D., Wu, Z., "A new topology of fault-current limiter and its parameters optimization," in PESC, pp. 462-465 Vol. 1, 2003.